Abstract

Ad hoc wireless networks are wireless networks without any fixed base station or any wireless backbone infrastructure The nodes use peer-to-peer packet transmission and multi hop routes to communicate with each other Each node acts as a router and forwards packets to the next node in the route Such networks are very useful in military and other tactical applications such as law enforcement, emergency rescue or exploration missions where cellular infrastructure is unavailable or unreliable

Mobile nodes operate on batteries with limited energy supply Thus efficient use of energy by the mobile nodes is very important in ad hoc wireless networks to increase the network's lifetime Some protocols reduce the topology of the ad hoc wireless network by electing cluster-heads or coordinators Routing protocols elect cluster-heads or cores (e g CEDAR) to decrease delay, reduce broadcast redundancy, increase energy efficiency and improve Quality of Service (QoS) Power saving coordination algorithms (e g Span) elect coordinators to make a backbone of active nodes that buffer packets for the sleeping nodes

For a given transmit power, directional antenna has longer range as compared to the omni-directional antenna The focus of this thesis is to effectively utilize the longer range property of directional antennas to increase distance between cluster-heads or coordinators This makes clustering and coordination protocols more energy efficient by forming "sparser" backbone network of cluster-heads and coordinators

The Network Interface Card (NIC) is a major cause of energy drain in a mobile node IEEE 802 11 defines a Power Saving Mode (PSM) in which nodes can power down their NIC and switch to doze or Sleep mode Span is a coordination algorithm that elects coordinators and form a backbone of active nodes The coordinators stay active (awake) and perform multi-hop packet routing Each node periodically broadcasts HELLO messages A decentralized coordinator election algorithm runs locally on each node using just the information received from the HELLO packets Span uses omni-directional antenna for communication between nodes. In this thesis, we have chosen Span, a power saving coordination algorithm for analyzing the effectiveness of directional antennas

In order to use directional antennas in ad hoc wireless networks, conventional Medium Access Control (MAC) protocols need to be modified Directional MAC (DMAC) protocol uses the directional RTS/CTS mechanism in order to adapt to directional antennas DMAC protocol is capable of exploiting spatial reuse But typically directional MAC protocols increase the problems of hidden node, deafness and unfairness New form of hidden node problems also arise due to "unheard RTS/CTS" and due to "unequal gain while transmitting and receiving"

Enhanced-Span(E-Span) is the coordination algorithm proposed in this thesis E-Span modifies Span and uses DMAC protocol In E-Span, protocol coordinators buffer and deliver data in a single transmission to the directional neighbors (i e two hop neighbors when using omni-directional antennas) In E-Span the elected coordinator also serves the directional neighbors as its direct neighbor Thus the number of neighbors of a coordinator node increases and the total number of coordinators, used for forming the backbone of a given network, reduces This makes the backbone sparser and thus using directional antenna, E-Span results in more energy efficiency when compared to Span Simulations of ad hoc wireless network running Span and E-Span validate the above claim and prove that E-Span is more energy efficient than Span

DMAC protocol has the unsolved problems of hidden node (due to unheard RTS/CTS and due to unequal gain while transmitting and receiving), deafness and unfairness, which degrade a network's performance The second contribution of this thesis is the design of a new directional MAC protocol called *Multiple-MAC*, which removes hidden node, deafness and unfairness problems and uses multiple directional antennas to exploit Space Division Multiple Access (SDMA) and spatial reuse

Multiple-MAC protocol proposes an architectural modification of the network stack in wireless nodes by the novel concept of "multiple MACs" The Multiple-MAC protocol uses Omni-directional RTS (ORTS) followed by Directional CTS (DCTS), Directional Data (DData) and Directional Ack (DAck) ORTS, DCTS are transmitted on the control channel and DData, DAck are transmitted on the data channel All packets in the control channel are transmitted at a fixed maximum power known to all the nodes in the ad hoc wireless network All packets transmitted in the data channel are power controlled using Transmit Power Control (TPC) The Negative-DCTS is a new transmission in our protocol, which removes the unfairness problem and improves throughput The protocol is also capable of establishing communication for real scenarios having non-line of sight nodes (due to obstacles) and removes duplicate packets (due to multi-path propagation). This is an on-demand (asynchronous) protocol. In an ad hoc wireless network, running Multiple-MAC protocol, a node can simultaneously behave as sender(s) and receiver(s) on different antennas

The Multiple-MAC protocol is evaluated through simulation study for four directional antennas Numerical results showed that the throughput performance of our protocol is dependent on the density of the network, topology of the nodes and the number of directional antennas For sparse networks with nodes located in separate spatial channels, the performance of Multiple-MAC protocol is a linear function of the number of directional antennas in use Thus Multiple-MAC protocol eliminates hidden node, deafness and unfairness problems and offers significant performance improvement when compared to that of omni-directional MAC protocols